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Strengthening of fibre reinforced concrete columns using high strength concrete filled steel tubes

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Abstract: *A large number of reinforced concrete (RC) structures over time have their usage altered, and they experience deterioration or damage caused by different causes. There are more than billions of tires used for replacement every year in global, and more than half of them are abandoned and are waiting to be disposed. The black pollution which is hard to be biodegrade does not only pose potential risks to the environment, but a threat to the health of human beings who work in the scrap zone. These are the two main issues that focused on this study. Different steel fibres like industrial steel fibre, recycled steel fibre and hybrid steel fibre are used for the construction of columns. Steel fibre obtained by the recycling of tyres are known as recycled steel fibres which reduces the dumping of tyres. The premade tested squared cross section fibre reinforced concrete columns was placed inside a steel tube and the space between the column and steel tube was filled with high strength concrete. The test results showed that the column with industrial steel fibres is having high strength compared to others. The influence of the test parameter on the compressive strength was investigated. In addition, specimen failure modes and load vs deformation relations were registered.*

Key Word: *Reinforced concrete, Industrial steel fibre, Recycled steel fibre, Hybrid steel fibre, Compressive strength.*

I.INTRODUCTION

1.1 General

A large number of reinforced concrete (RC) structures over time have their usage altered, and they experience deterioration or damage caused by different causes. RC elements are often degraded by enlarged loads, inadequate maintenance, a more aggressive environment, etc. There are more than billions of tires used for replacement every year in global, and more than half of them are abandoned and are waiting to be disposed. The black pollution which is hard to be biodegrade does not only pose potential risks to the environment, but a threat to the health of human beings who work in the scrap zone. there are mainly three types of recycling materials recovered from waste tires, and they are rubber, waste steels and scraps respectively. Moreover, the resident tensile strength of waste steel keeping in high level, and some researchers are trying to apply its high strength in construction. In the mentioned situations the waste steel also known as steel fibre is used to construct the column and a steel jacket filled with high strength concrete used to strengthen the fibre reinforced concrete columns. Square columns with industrial steel fibre(ISF), recycled steel fibre(RSF) and hybrid steel fibre(HSF) are placing inside a steel tube and then the space between the column and the tube is filling with high strength concrete.

1.2 Fibre Reinforced Concrete Columns

In order to improve the tensile strength and reduce the risks of brittle failure, adding fibres in the concrete mixture is an excellent solution. Fibers are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter resistance in concrete. Larger steel or synthetic fibers can replace rebar or steel completely in certain situations. Fiber reinforced concrete has all but completely replaced bar in underground construction industry such as tunnel segments where almost all tunnel linings are fiber reinforced of using rebar. This may, in part, be due to issues relating to oxidation or corrosion of steel reinforcements. This can occur in climates that are subjected to water or intense and repeated moisture, see Surfside Building Collapse. Indeed, some fibers actually reduce the compressive strength of concrete.

ISF is one of the most commonly used fibre materials. The adding of ISF in concrete is beneficial to controlling the development of the crack. It shows a good improvement of the brittle matrix, especially in terms of toughness and post-cracking behaviors. Adding fibre plays an important role in increasing the tensile strength of concrete. RSF shows better performance at the beginning of the happening of crack. The compressive strength of RSF concrete decreases with the increase of fibre content when the fibre content higher than 0.5%. The RSF shows good performance in improving the splitting strength of concrete. It has low greenhouse gases emissions and low price than ISF. RSF have reliable performance in improving the mechanical properties of concrete.

Fig 1: Fibre reinforced concrete

Fig 2: Industrial steel fibre

Fig 3: Recycled steel fibre

1.3 Strengthening of Fibre Reinforced Column

It is a solution provided when the structure is incapable of carrying more load. It is the process of restoring structures. It avoids the entire collapse of a structure and improves its capacity. Strengthening is better than reconstruction, as reconstruction has disadvantages such as material cost, labour cost, time consumption etc. Strengthening is making changes to an existing building in order to protect it from natural hazards. Repair can lead to increased stiffness, strength, and failure deformation. Thus, HSC and steel tube is used to improve the overall properties of fibre reinforced concrete columns. Concrete filled steel tube (CFST) typically consists of rectangular or circular steel tubes filled with concrete. It is superior to the plain concrete and steel counterparts in the following aspects: (i) the synergistic action between steel tube and concrete infill improves the strength and ductility of concrete infill and delays the local buckling of steel tube; (ii) the use of steel tube eliminates the need for formwork, which in turn reduces the construction time and costs; and (iii) the fire resistance and blast resistance are both enhanced due to the confinement of steel tube on concrete infill. As a result, CFST members have been widely used in buildings, bridges, piles, and transmission towers among other structures.

Concrete-filled steel tube (CFST) members have higher strength and ductility as compared to steel or reinforced concrete members. The lateral expansion of the concrete infill is restrained by the confinement of the steel tube, and the local buckling of steel tube is delayed by the concrete infill. It increases the compressive strength of concrete.

Fig 4: High strength CFST

II.EXPERIMENTAL PROGRAM

2.1 Test Specimen Details

A total of four specimens with length 900mm were fabricated and tested in this study. All the specimens were tested and the tested columns containing ISF, RSF and HSF including control columns are placed inside the steel tube having external diameter 200 mm and the thickness 3 mm, then the space between the steel tube and the column is filled with high strength concrete of grade M40. The first case is control columns of M20, second case is the adding of industrial steel fibre of amount about 0.5% to the concrete mix, third case is adding of recycled steel fibre of amount about 0.5% to the concrete mix and the last case is the combination of both industrial steel fibre and recycled steel fibre as 50% each. The dimension of the column is 120mm x 120mm cross section and the height of the column is 900mm. The main bar used is 4 numbers of 10mm diameter and the stirrup used is 8 numbers of 6mm diameter at 120mm c/c spacing.

Table 1: Details of specimen

.Specimen details

Cross section of Column	120 x 120mm
Height of Column	900 mm
Diameter of Main bar	10mm
Diameter of Ties	6 mm
Grade of normal concrete column	M20
Grade of HSC	M40
Diameter Steel tube	200 mm
Thickness of Steel tube	3 mm
Loading Condition	Static compressive loading
Type of Column	Short column

Table 2: Material property

Specimen	**Density (Kg/m^3)**	**Elastic Modulus (GPa)**	**Poissons Ratio**	**Yeild Strength (MPa)**
Steel tube	7850	200	0.3	240
Rebar	7850	205	0.29	500
Concrete (M40)	2400	31.62	0.2	3.4
Concrete (M20)	2400	22.36	0.2	2.7
ISF Concrete	1901	31.35	0.3	3.06
RSF Concrete	1901	31.35	0.3	3.64
HSF Concrete	1901	31.35	0.3	3.31

2.2 Specimen Preparations

Specimen preparation having following steps:

1. Preparation of formwork: The moulds for the casting of columns were prepared using plywood and inch nails in the laboratory.

2. Preparation of reinforcement: Reinforcement is commonly used to enhance the column's strength, ductility, and resistance to bending moments induced by the load. 4 nos. of 10 mm bars were provided as the main bar and 8 nos. of 6 mm bars were provided as the stirrups at 120mm c/c spacing.

3. Casting of columns: The casting process involves the construction of the column using formwork and pouring concrete into the formwork to create the desired shape. The required quantities of cement, coarse aggregate, fine aggregate and steel fibres are mixed uniformly by hand mixing, and the required quantities of water are added to the mix.

4. Curing: Curing is a critical process that involves maintaining the adequate moisture and temperature conditions of freshly placed concrete to ensure proper hydration and the development of its desired strength and durability.

Fig 5: Formwork preparation

Fig 6: Reinforcement preparation

Fig 7: Casting of column

Fig 8: Curing of column

5. Casting of strengthened column: The column after testing is strengthened by placing a steel tube around the tested columns and filling the space between with high strength concrete.
6. Curing of strengthened columns: Strengthened column is cured using gunny bags.

Fig 9: Mixing of HSC

Fig 10: Casting of HSC

Fig 11: Curing

2.3 Instrumentation and Test Setup

The specimens were fixed support and tested under static compressive loading applied at the top of the specimen. Testing machine is UTM for RC column and for strengthened column the testing conducted in loading frame and load applied manually by using hydraulic jack. Linear variable displacement transformers (LVDTs) were installed to measure the displacements of the specimen. A data logger and an electronic digital indicator is used to measure displacement and load respectively.

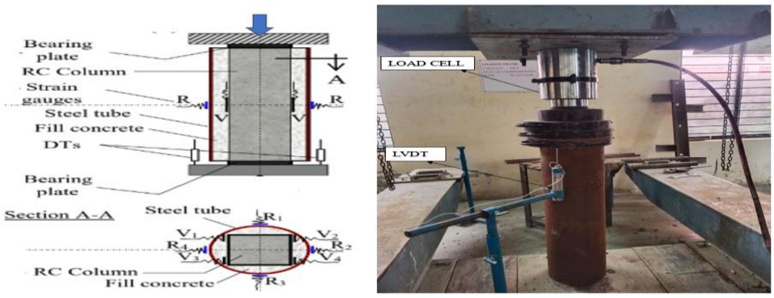

Fig 12: Experimental test set up

III. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Experiment Observations and Failure Modes

The inner RC column tested in the UTM has hairline cracks appear as the load increases. Crushing of concrete takes place at the top of the column and the ISF reinforced column shows high load bearing capacity. The strengthened column tested in the loading frame having failure of all reinforced columns resulted from a combination of factors: the outward buckling of the steel jacket and the crushing of concrete due to excessive compressive forces. Strengthening the columns proved effective in enhancing their ductility, a vital characteristic for structural resilience. Although small cracks appeared in the concrete fill, the core of the columns remained intact, free from any detectable damage. The application of a steel jacket exerted confinement pressure, effectively preserving the integrity of the concrete.

The four specimens noticed same type of failure modes. As increase of the load caused stretching of the steel jacket, which had a consequence on the bonds between the steel tube, the concrete fill, and the basic RC column. Subsequently, the steel jacket could not provide efficient confinement to the fill concrete, which resulted in the crushing of the basic RC column. It was found that the steel tubes had some buckling in the outward direction and small cracks in the fill concrete. Cracks were located around the corners of the RC column in the radial direction. No cracks were detected in the core RC column. Dissimilar to the crushing failure of plain RC columns, the concrete in strengthened columns can keep its integrity because of the confinement pressure produced by the steel jacket.

3.2 Load – Deflection Behaviour of Specimens

In this initial stage, the columns deflection increases linearly. The relationship between the load and deflection is linear, indicating that the material behaves elastically. During this phase, the column is within its elastic limit, meaning that it will return to its original shape if the load is removed. The stiffness of the column is constant in this region, and no permanent deformation occurs. When the curve starts to deviate from linearity, indicating the onset of non-linear behavior. In this transition phase, the material begins to yield and plastic deformation starts to occur. The stiffness of the beam decreases as it approaches its ultimate load capacity. Micro-cracking, yielding of materials, or other forms of non-linear behavior may begin in this region. The column is transitioning from elastic behavior to a plastic state, where permanent deformations start to develop. After reaching the peak load the load begins to decrease even as deflection continues to increase. This stage represents the post-peak behavior of the column. The column has surpassed its maximum load-bearing capacity, and damage is accumulating. Significant plastic deformation occurs, and the stiffness of the column further decreases. This descending branch indicates the failure or significant degradation of the columns structural integrity. The columns material might be experiencing crushing, extensive cracking, or other forms of damage that lead to a reduction in load-carrying capacity.

Fig 13: Different failure modes of RC column

Table 5: Failure load values of RC column

Specimen Type	Load (kN)	Deformation (mm)
Control Column	301	1.1
Industrial steel fibre reinforced concrete column	354	1.5
Recycled steel fibre reinforced concrete column	332	1.1
Hybrid steel fibre reinforced concrete column	342	1.2

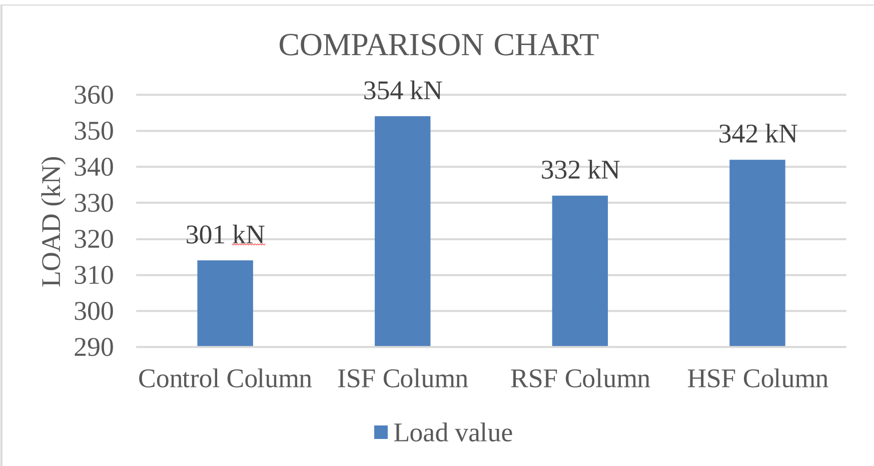

Fig 14: Load carrying capacity of RC column

Fig 15: Different failure modes of strengthened columns

Table 6: Failure load values of strengthened column

SI No.	Specimen Type	Load at failure (kN)
1	Control column	856
2	ISF concrete column	952
3	RSF concrete column	886
4	HSF concrete column	910

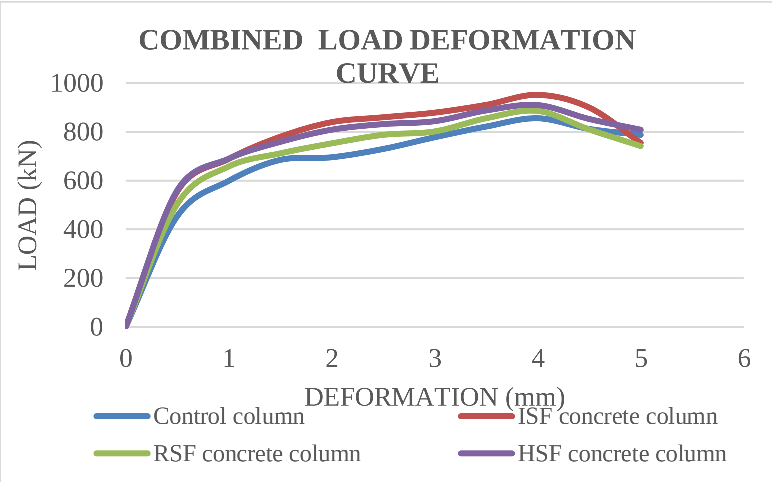

Fig 16: Load deformation curve of strengthened column

3.3 Analysis of Columns Before and After Strengthening

The main difference between columns before and after strengthening, besides greater strength, was ductility. The strengthened column had a large deformation capacity and the ability to restrain the pronounced development of cracks in concrete. Hence the ductility is high for strengthened columns when compared with RC columns.

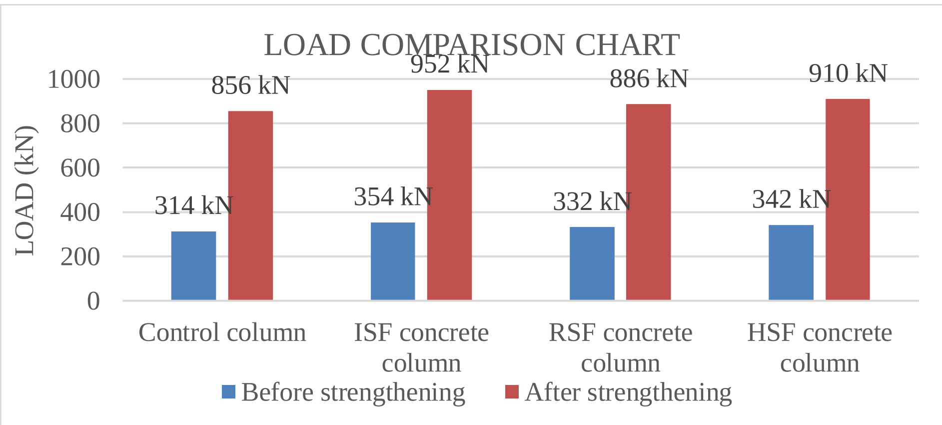

Fig 17: Load comparison chart before and after strengthening

From the chart it is clear that a huge difference was occurred in the strength and deformation values before and after strengthening. The industrial steel fibre columns is having high load bearing capacity and deformation value compared to other specimens.

IV. CONCLUSIONS

Four type specimens were tested under static compressive loading. The results of failure modes and load–deflection behavior are obtained. The main findings are summarized below:

1. The project endeavors to enhance the structural integrity of ISF, RSF, and HSF concrete columns through the implementation of HSC filled steel tubes. By integrating these high-strength concrete (HSC) filled tubes within the columns, the structural resilience and load-bearing capacity can be significantly bolstered. This innovative approach not only reinforces the columns against various external forces but also mitigates potential risks such as corrosion and buckling, thereby extending the lifespan of the structure.
2. The selection of steel fibers at a percentage of 0.5% has been determined through meticulous testing procedures involving cube and cylinder tests. These tests are essential for evaluating the performance and durability of the concrete mixture when reinforced with steel fibers. The chosen percentage of 0.5% strikes a balance between reinforcing the concrete matrix without compromising its workability or structural integrity.
3. The integration of Recycled Steel Fibers (RSF) into concrete presents a compelling proposition, offering significant economic and environmental advantages. Studies have shown that substituting RSF at a concentration of 0.5% can yield remarkable results. Not only does this substitution reduce emissions by up to 25%, contributing to a greener construction process, but it also demonstrates notable cost savings, with prices potentially decreasing by as much as 28%. This dual benefit addresses both environmental concerns and economic considerations, making RSF an attractive option for sustainable construction practices.
4. ISF provides enhanced ductility and crack resistance to the concrete matrix due to its uniform distribution throughout the material. This inherent toughness allows ISF-reinforced concrete to withstand higher loads and deformations before failure occurs. The bonding between the steel fibers and the concrete matrix ensures efficient load transfer, optimizing the material's overall performance under various loading conditions. The consistent and reliable behavior of ISF-reinforced concrete, demonstrated by its superior load-carrying capacity both before and after strengthening, underscores its effectiveness as a versatile and resilient construction material.
5. The failure observed in the composite column was a dual mechanism involving both outward buckling of the steel tube and crushing of the concrete due to an excess of compressive strength. This combination of failure modes highlights the complex interaction between the steel and concrete components within the composite structure. By addressing both the buckling behavior of the steel tube and the compressive strength of the concrete, future designs can strive to mitigate such failure modes, thereby enhancing the overall performance and reliability of composite structural elements.
6. The observed increase in deformation values following the strengthening process corresponds to a notable enhancement in the ductility of the column. Ductility, a critical property in structural engineering, denotes the material's ability to undergo significant deformation prior to failure. By increasing the column's ductility through strengthening measures, such as the incorporation of additional reinforcement or the introduction of composite materials, engineers can effectively enhance the structural performance and safety margin of the system.

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